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NORDIC MULTI-STOREY TIMBER BUILDINGS FOR RESIDENTIAL HOUSING

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ABSTRACT
It is generally accepted that noise disturbance from footfall noise is one of the greatest challenges in development of multi-storey timber buildings for residential housing. Residents describe this annoyance as low frequency "thumps". This paper focuses on how to design the building to give good sound properties that people are satisfied with. It gives a special attention to the lightweight timber floor constructions: how to ensure good low-frequency impact sound insulation and how it can be measured and evaluated to give a good correlation to subjective scores.

1 - INTRODUCTION
The Nordic research programme Nordic R&D project "Multi-storey timber frame buildings" has promoted a large number of pilot-building projects during the last 2-3 years. The sound insulation properties of different solutions have been investigated and compared with the subjective degree of annoyance related to measuring values. In order to make it possible to evaluate and classify the floors in the pilot building projects and future floor constructions, it was necessary to find alternatives to the standard ISO method that had proved to be unsuitable.
The project has financed a new publication [1] published by the Norwegian Building Research Institute in March 2000: "Multi-storey timber houses. Acoustic design" (written in Norwegian). Responsible for this publication has been Sigurd Hveem (Norway) in co-operation with Jens Holger Rindel (Denmark), Asko Keronen (Finland), Anders Homb (Norway) and Per Hammer (Sweden). This design manual gives examples of the best choice of design including the variety that covers the different building traditions in the Nordic countries securing high-quality acoustic performance. It contents examples of floors and separating walls with connecting details to outer walls, inner walls, separating walls and corridors. It also shows examples of floors in bathroom, staircase, corridors and lift and technical installations (HVAC). In this paper we will focus on the floor construction.

2 - RATING OF IMPACT SOUND INSULATION
From earlier experience with lightweight buildings we knew that low frequency sound would be the most important issue to solve, especially concerning noise from footsteps. The project has stated that national requirements based upon the ISO-method rating are not suitable to ensure high quality acoustic performance. Low-frequency rating is absolutely necessary and when you include the new recommended additional C-factor from 50 Hz, the rating are then much better correlated to subjective scores. However, it seems that the rating method proposed by Bodlund in 1985 [2] but still using the ISO tapping machine, gives an even better judgement. From figure 1 you can see that this method also includes the low frequency bands 50, 63 and 80 Hz, but in addition the low frequency rating is much stronger. The good thing is that we still can use the standard tapping machine. Other standard sources have also been tested, for instance the proposed rubber ball method from Japan.

3 - RECOMMENDED VALUES FOR SOUND INSULATION
The recommended limits for sound insulation between dwellings stated in the project "Multi-storey timber buildings" are given in the table. A special focus has also been put on special problems on vibration and deflection of lightweight floors. This is an important property, especially when you are handling floors with long spans from 5-8 meters.

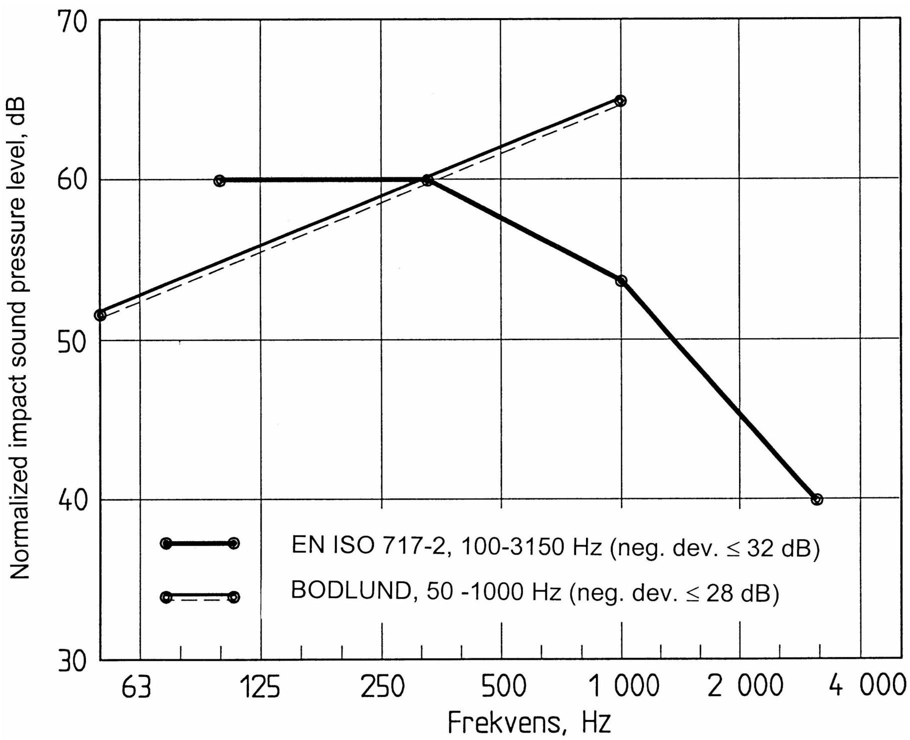

Figure 1: Reference-curves for impact sound.

Airborne sound insulation according to EN ISO 717-1	Impact sound insulation according to EN ISO 717-2	Bodlund's index for impact sound insulation
$R'_w + C_{I,50-5000}$	$L'_{n,w} + C_{50-2500}$	L_s
≥ 55 dB	≤ 53 dB	≤ 62 dB

Table 1: Recommended limits for sound insulation between dwellings.

4 - EXAMPLES OF FLOORS

In figures 2 and 3 we give two typical examples of timber floor constructions that has been used in pilot building projects. Here we only show the floor construction itself without connecting details, although this is an important part as to flanking conditions.

In general, the floors are rather stiff with high joist compared to the actual span. The elastic suspended ceiling is a good traditional solutions that are effective to as well impact sound as airborne sound. The cavity is more or less filled with mineral wool. Figure 2 shows the floor construction in the Norwegian pilot building.

Figure 3 shows an example from Sweden which is a copy of how they build floors in multi-storey residential building in USA with 30 mm of gypsum concrete on a rubber layer.

5 - MEASUREMENTS OF SOUND PROPERTIES

Table 2 shows the results of the sound insulation from 9 Nordic pilot buildings. The results are given by different rating values.

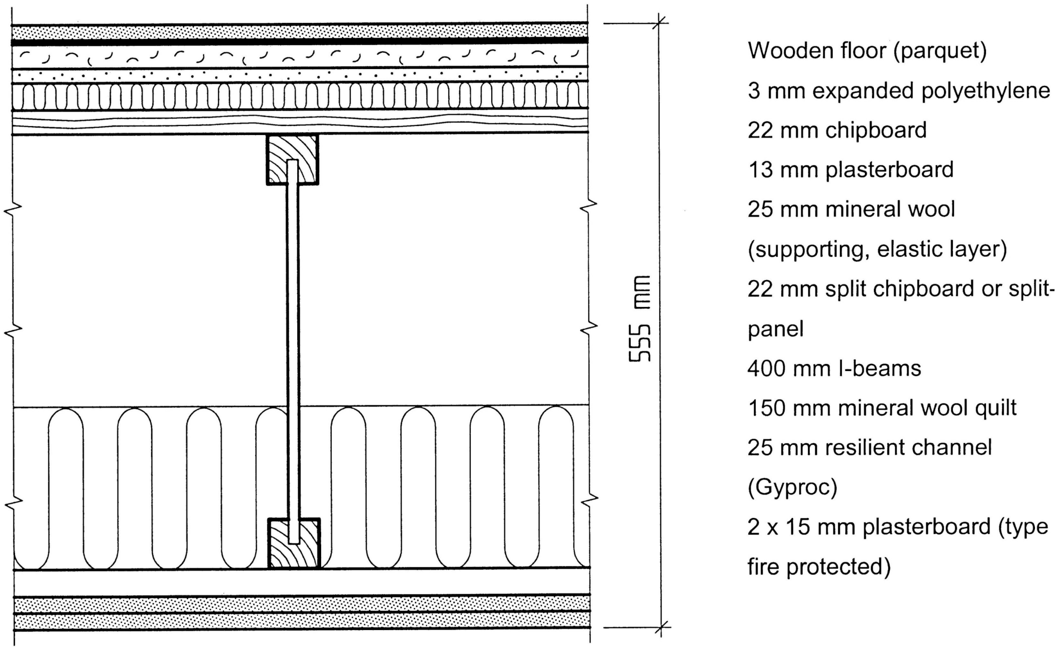

Figure 2: Solbakken (Norway).

Pilot project		Total thickness mm (approx.)	$L'_{n,w}$ dB	$L'_{n,w} + C_{I,50-2500}$ dB	L_s dB	R'_w dB	$R'_w + C_{50-5000}$ dB
Casa Nova (Hørsholm)	DK	375	44 – 47	52 – 54	58 – 62	59 – 63	–
Casa Nova (Herning)	DK	375	ca. 50	–	–	ca. 58	–
Ylöjärvi[1)]	FIN	487	36 – 44	41 – 47	49 – 56	62 – 67	–
Vik/Viikki	FIN	400	48 – 53	54 – 58	62 – 67	58 – 62	–
Uleåborg/Oulu (RL-slab)	FIN	407	44 – 49	49 – 54	55 – 62	61 – 65	–
Uleåborg/Oulu (I-beam)	FIN	505	51 – 54	54 – 57	62 – 66	61 – 65	–
Solbakken	N	555	46 – 48	58 – 60[1)]	65 – 66	62 – 65	58 – 59
Wälludden	S	439	50 – 52	52 – 54	60 – 62	56 – 58	55 – 56
Orgelbänken	S	530	48 – 51	50 – 52	57 – 59	60 – 63	56 – 59

Table 2: Results of the sound insulation measurements given by different ratings ([1)] relatively bad low-frequency properties gives high value for the spectrum adaptation term in the extended frequency range).

Table 2 shows the great difference we find between the rating values. Figure 4 shows the normalized impact sound pressure level in 1/3 octave bands from the different Nordic pilot projects compared with a traditional floor construction in Norway. We can here study the great differences between the constructions. The low frequency range is especially decisive.

6 - SUBJECTIVE SCORES

The interesting part is to compare the results from table 2 with the subjective scores from the interviews of the users of the buildings. Here we give a short summary of the scores for sound from footsteps on the floors. For the moment we have no interviews from the Danish projects Casa Nova. In the Finnish projects we can see that the rating values according to ISO 717-2 are very good for the Ylöjärvi project, but for some reason it seems to give a rather bad score. The scores for the constructions with floating floor on mineral wool are generally not so good, especially for the Vik and Uleĺborg (I-beam)

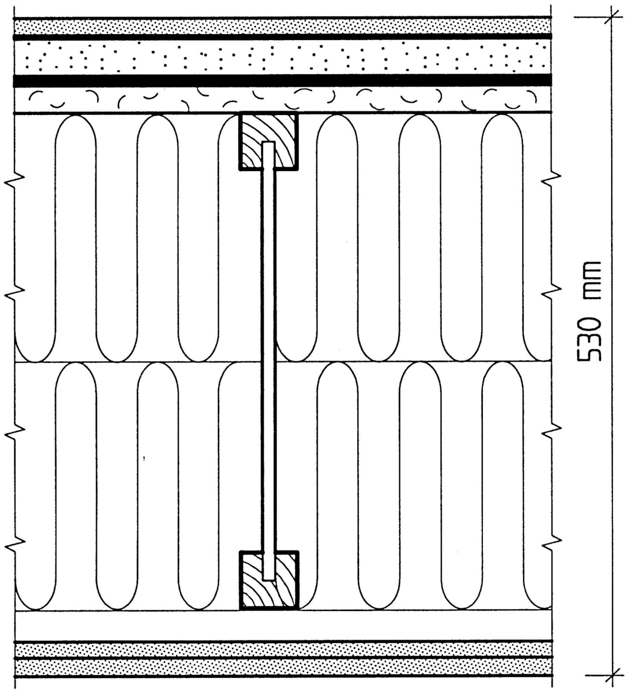

Figure 3: Orgelbänken (Sweden).

projects. The scores are better for Uleĺborg (RL combination for the solution with a 60-mm concrete slab. In the Norwegian project Solbakken we have very few interviews, but the subjective reaction on the impact sound properties for the floor with floating floor on mineral wool is clearly negative. In the Swedish projects the scores are rather good (about 5 on a scale from 1-7). Here we have both stiffer and heavier floors without use of elastic layers of mineral wool. The score for airborne sound insulation of the separating floors are very good. Although the interviews are few, it seems that we have verified that the $L'_{n,w}$ value alone is not suitable. In addition, our material also seems to verify that people accept the impact sound properties as long as $L'_{n,w} + C_{I,50-2500} \leq 53$ dB or if Bodlunds index $L_s \leq 62$ dB.

7 - CONCLUSIONS

We can here conclude that the Nordic R&D project "Multi-storey timber frame buildings" have led to new and better separating floor constructions which people are satisfied with. It is absolutely possible to handle sound insulation problem in lightweight constructions, but the choice of floor-construction is quite decisive. The airborne sound insulation (weighted apparent sound reduction index, R'_w) is ordinarily satisfying, if the impact sound insulation is fairly good. For more details and specification of separating and connecting constructions, see NBI guideline no. 37 [1].

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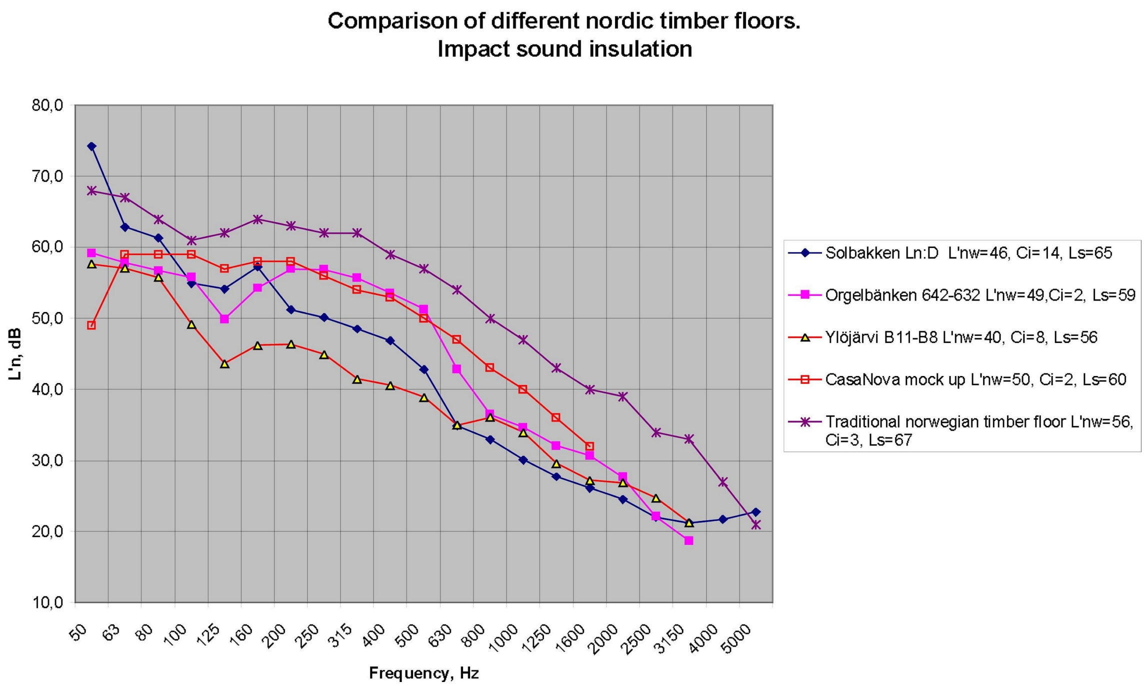

Figure 4: Results of impact sound insulation of the different Nordic pilot projects.